REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August, 2007	Proceedings Article

4. TITLE AND SUBTITLE
THERMAL MANIKIN EVALUATION OF PASSIVE AND ACTIVE COOLING GARMENTS TO IMPROVE COMFORT OF MILITARY BODY ARMOR.

5. FUNDING NUMBERS

6. AUTHOR(S)
Thomas Endrusick, Julio Gonzalez and Larry Berglund

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Biophysics and Biomedical Modeling Division
U.S. Army Research Institute of Environmental Medicine
Building 42 - Kansas Street
Natick, MA 01760

8. PERFORMING ORGANIZATION REPORT NUMBER
M07-38

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, MD 21702

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This study evaluated two different garments designed to increase ventilation and evaporative cooling under Interceptor Body Armor: a passive, Interceptor Ventilation Vest (IVV); and an active, battery-powered, Body Ventilation System (BVS). Both were tested for thermal (Rt, m2€W-1) and evaporative resistance (Re, m2PaW-1) on a thermal manikin (TM), according to ASTM standards. TM results showed Rt and Re increased (16% and 26%, respectively) when IBA was worn. However, increases were lower (9% and 14%) with IVV under IBA. These lowered resistances increased TM evaporative cooling potential approximately 15%. With the BVS blower unit ON, TM measurements of Rt and Re were lower (17% and 20%), when compared to OFF values. This increased TM evaporative cooling potential approximately 18%. Military use of these garments could allow for increases in sweat evaporation and overall thermal comfort during operational heat exposure.

14. SUBJECT TERMS
thermal manikin, Interceptor Body Armor, evaporative cooling, thermal comfort.

15. NUMBER OF PAGES
4

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

THERMAL MANIKIN EVALUATION OF PASSIVE AND ACTIVE COOLING GARMENTS TO IMPROVE COMFORT OF MILITARY BODY ARMOUR

Thomas Endrusick, Julio Gonzalez and Larry Berglund
Biophysics and Biomedical Modeling Division, U.S. Army Research Institute of Environmental Medicine, Natick, Massachusetts, USA.
Contact person: thomas.endrusick@us.army.mil

INTRODUCTION

U.S. military forces are currently using the Interceptor Body Armour (IBA) system consisting of a front/rear torso fragmentation vest, front/rear ballistic plates, and optional attachments for throat, groin, upper arm, and side torso protection. When fully configured, the IBA can weigh 15 kg and cover upwards of 30% of the body surface area, with multiple layers of low-permeability materials. Use of the IBA can contribute to heat stress and limit wearer performance by insulating the body and reducing body heat loss. Wearing body armour has been associated with increasing the wet bulb globe temperature around the wearer by about 4^{o}C (1). The negative impact of heat stress and dehydration on soldier performance is well recognized by the U.S. Military (2). It is hypothesized that an increase in evaporative cooling could reduce overall sweat rates and consequent soldier dehydration. This study evaluated two different garments designed to increase air ventilation and subsequent evaporative cooling under the IBA: a passive, Interceptor Ventilation Vest (IVV); and an active, battery-powered, Body Ventilation System (BVS).

METHODS

The IVV was made from synthetic mesh material with a total weight of 0.29 kg and was designed to be worn directly under the IBA. It was tested for thermal (R_t, $m^2{\cdot}C{\cdot}W^{-1}$) and evaporative resistance (R_e, $m^2{\cdot}kPa{\cdot}W^{-1}$) on a thermal manikin (TM), according to ASTM standards (3, 4). The TM was dressed in 3 configurations: with the U.S. Army Temperate Battle Dress Uniform (TBDU); with IBA over TBDU; and with IBA over both IVV and TBDU. TM results were used as input to a computer model predicting core temperature (T_c, ^{o}C), skin temperature (T_{sk}, ^{o}C), heart rate (HR bpm), sweat rate (SR g/min), skin wettedness (SW %), and total body water loss (WL L). Output described responses when exposed to desert environments with air temperatures of 30, 40 and 50^{o}C during repeated, intermittent exercise (10 min rest/ 30 min walk).

The BVS consisted of a battery-powered blower unit that delivered an inlet flow rate of approximately 9 $l{\cdot}s^{-1}$ of ambient air through a distribution manifold into a channelled spacer vest worn directly under the IBA. Total system weight was 2.5 kg. R_t, R_e, and cooling power (W) were measured according to applicable ASTM standards (3, 4, 5) with the TM dressed in the U.S. Army Desert Battle Dress Uniform (DBDU). When measuring cooling power, the sweating TM was allowed to reach equilibrium at T_{sk} of 35°C while wearing the BVS with the blower unit OFF. After equilibrium was achieved, the blower unit was turned ON. The TM was allowed to run until steady state conditions were maintained for two hours. The BVS cooling power was calculated by subtracting the OFF steady state TM power demand from the ON steady state TM power demand.

RESULTS

Interceptor Ventilation Vest: Table 1 shows that TM R_t and R_e increased (15% and 45%, respectively) when only IBA was worn over TBDU. However, increases in R_t and R_e were lower (10% and 25%) when adding the IVV under IBA. The familiar permeability index ratio (i_m/clo) is also included in Table 1 for comparison purposes.

Table 1. Total Thermal Manikin (TM) thermal (R_t) and water vapour resistance (R_e) for the various configurations of the Temperate Battle Dress Uniform (TBDU), Interceptor Body Armour (IBA), and Interceptor Ventilator Vest (IVV).

Clothing configuration	R_t	R_e	i_m/clo*
TBDU	0.226	0.024	0.29
TBDU+IBA	0.265	0.044	0.16
TBDU+IBA+ IVV	0.251	0.032	0.22

* included for comparison purposes

Figure 1 shows that use of the IVV reduces SW, particularly during rest periods. However, in this modelled scenario, SW remains above approximately 50%, which would probably be perceived as uncomfortable by most wearers. Figure 2 shows that SR is lower when wearing the IVV and this could lessen rates of dehydration while improving both physical and cognitive performance and decreasing the risk of heat injury (2). Figure 3 shows use of the IVV resulted in consistently lower T_c throughout the entire simulated exposure even at the highest ambient temperature of 50°C. Overall, the model results predicted thermo-physiological benefits when using an IVV with lower SW at 30°C, lower T_c, Tsk, HR, SR, and WL at 40°C and lower T_c at 50°C.

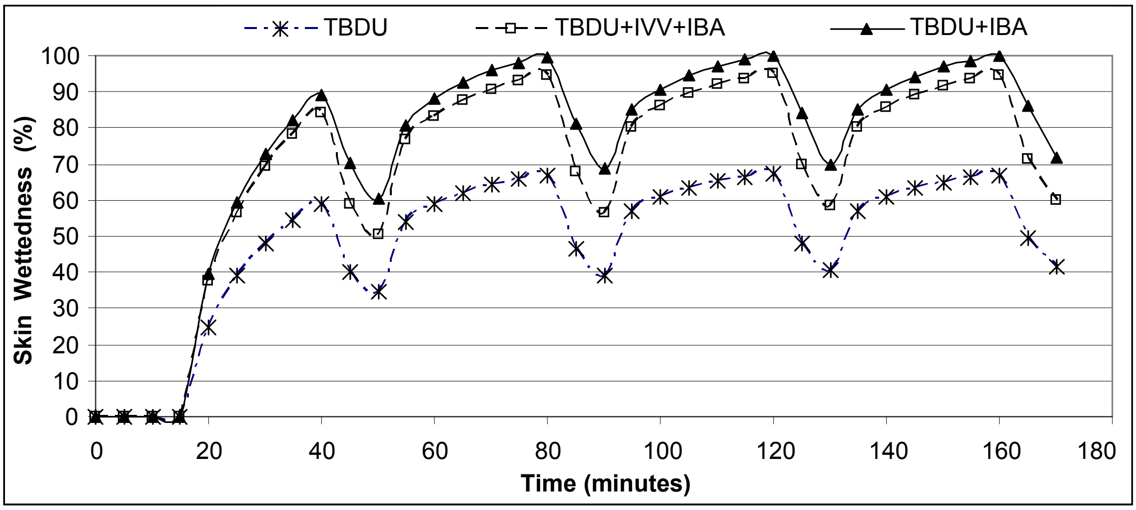

Figure 1. Predictive model results of skin wettedness (SW, %) for the 3 clothing configurations at 30°C.

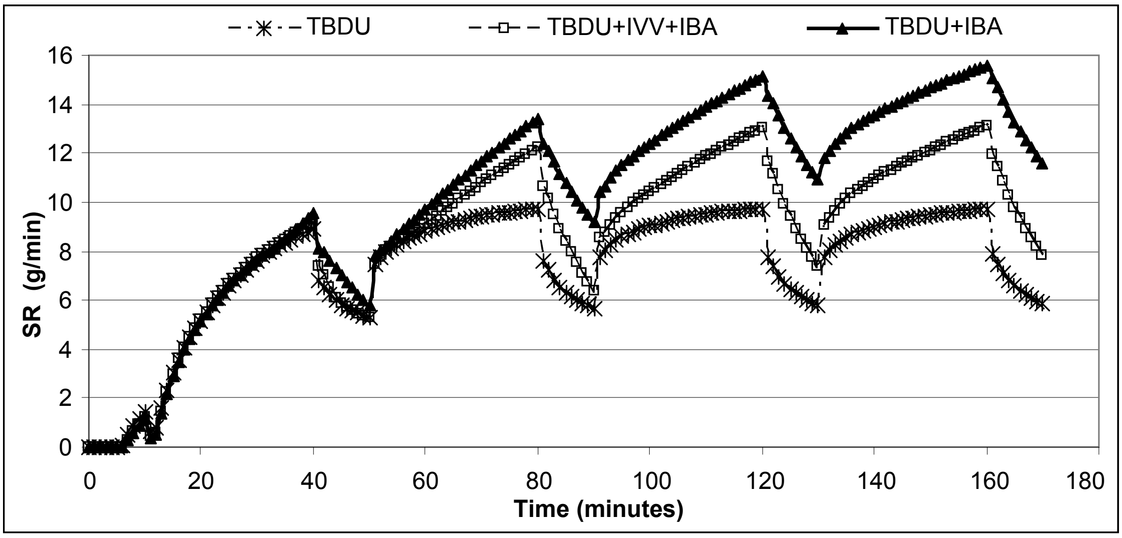

Figure 2. Predictive model results: sweat rate for three clothing configurations (40°C)

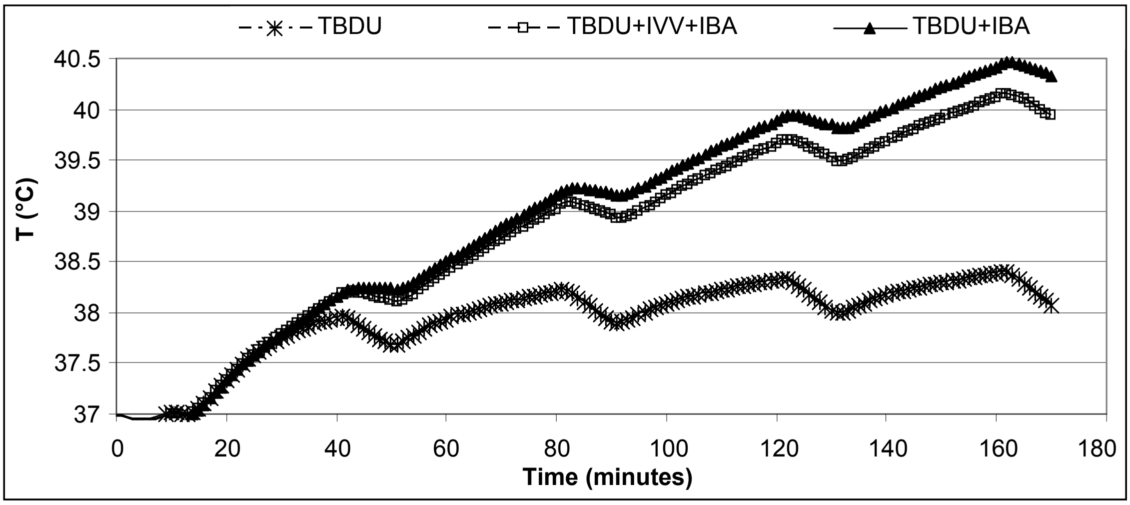

Figure 3. Predictive model results: core temperature for three clothing configurations (50°C).

Body Ventilation System: With the BVS blower unit ON, TM measurements of R_t and R_e from the BVS/DBDU ensemble were lower (17% and 20%), when compared to OFF values. Subtracting the average power input with the BVS fan OFF from the average with it ON resulted in an average cooling power of 45.1 W associated with the BVS forced ventilation of 9 l•s^{-1} (Figure 4) Though untested, the cooling capacity would be expected to increase at a lower ambient humidity.

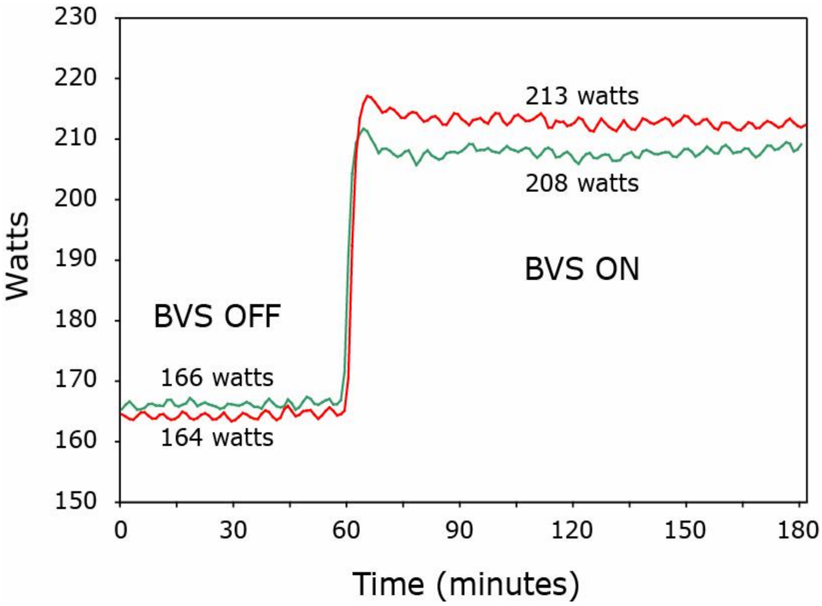

Figure 4. Power input to the TM with a constant 35°C surface temperature during OFF and ON operation of BVS.

DISCUSSION

It must be stated that these results were obtained from tests conducted under controlled environmental conditions using a stationary TM. The actual field performance of both garments will probably vary due to a multitude of factors including garment fit/configuration, body posture, and prevailing weather conditions. Nevertheless, these laboratory experiments showed that specialized garments designed to increase air circulation around the human torso reduced the inherent thermal burden of overlying body armour. Military use of these garments could allow for increases in sweat evaporation and overall thermal comfort during operational heat exposure.

REFERENCES

1. Goldman, R (1969). Physiological costs of body armour. Military Medicine, 134 (3):204-210.
2. Departments of the Army and Air Force. Heat stress control and heat casualty management. Washington, D.C.: Headquarters Department of the Army and Air Force, 2003.
3. ASTM Standard F 1291-99. Standard Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin. ASTM International, West Conshohocken, PA, USA .
4. ASTM Standard F 2370-05. Standard Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin. ASTM International, West Conshohocken, PA, USA.
5. ASTM Standard F 2371-05. Standard Test Method for Measuring the Heat Removal Rate of Personal Cooling Systems Using a Sweating Heated Manikin. ASTM International, West Conshohocken, PA, USA.